A PRESTRESSED CONCRETE VIADUCT IN THE NASU-DUKURI AREA ON THE SECOND KEIHAN EXPRESSWAY

Yoshiro OOKUNI[1), Yoshihiko TAIRA[2), Shinsuke KAWANO[3) and Kei MURODA[4)

[1) Naniwa National Highway Office, MLIT, Osaka, Japan, ookuni-y86ze@kkr.mlit.go.jp
[2) Sumitomo Mitsui Construction, Co., Ltd., Tokyo, Japan, ytaira@smcon.co.jp
[3) Sumitomo Mitsui Construction, Co., Ltd., Osaka, Japan, shinkawano@smcon.co.jp
[4) Sumitomo Mitsui Construction, Co., Ltd., Osaka, Japan, kmuroda@smcon.co.jp

ABSTRACT

The prestressed concrete viaduct in the Nasu-dukuri Area on the Second Keihan Expressway is located in Hirakata and Katano, Osaka, Japan. The viaduct is a 20 spans continuous box girder with the total length of 790 m. The superstructure consists of four single cell girders, which is used as typical cross-section on the Second Keihan Expressway. Each girder has a constant configuration of width and height.

In case that it is difficult to have enough casting yard and stock yard such as in the urban viaduct project, factory-prefabricated segmental construction is one of the effective solutions, that is generally thought to be the concrete structures with high quality, the reduction of construction work and the cost saving in the large-scale project. In order to improve the conventional segmental construction, another precast segmental construction using the U-shaped girders without upper slab was applied. The girders were cast and stocked at relatively narrow casting yard utilizing the sideway in the construction site due to the limited site conditions. This paper describes the general features of the project.

1. OVERVIEW OF THE PROJECT

The Second Keihan Expressway linking Osaka and Kyoto has the total length of 28.3km and is planed to be the bypass of the existing National Route 1. It has 6 lanes driveway and 2-4 lanes in order to release the chronic traffic congestion. Since the expressway is constructed in the residential area, the expressway is considered for both the environmental protection and the aesthetics.

The Nasu-dukuri Area is located in the districts of Hirakata City and Katano City, Osaka. The project consists of the construction of 5 viaducts; 20 and 2@2 spans exclusive viaducts, and 7 spans on and off lamps (Table-1). The main section of the exclusive viaduct of the 20 spans continuous viaduct has the total length of 790 meter (Fig.-1, Fig.-2, Fig.-3 and Photo-1).

Table-1 Properties of the viaduct

Project	Viaduct in Nasu-dukuri Area on the Second Keihan Expressway
Structure	(20,2@2,2@7) spans prestressed concrete viaduct
Length	20 spans viaduct: 790m 2@2 spans viaduct: 2@108m 7 spans viaduct (on lump): 278m 7 spans iaduct (off lump): 271m
Spans	max. length 42m
Effective width	29.64m

Generally, the conventional span-by-span erection is often used for the continuous viaduct using precast segments where the girder was divided into several segments and the segments are fabricated and stocked in the casting yard near the site or the existing concrete factories. However for this construction method, relatively large erection girder was required since all the precast segments have to be lifted or supported by the erection girder. Moreover in the urban area, It may be difficult to have enough casting yard or stock yard. Therefore, more rational construction method was required for the construction of the 20 spans viaduct in the viaduct in the Nasu-dukuri Area. A unique U-shaped girder lifting erection method was developed in order for the time reduction, the cost saving, the quality assurance and the reduction of environmental damage during construction, etc.

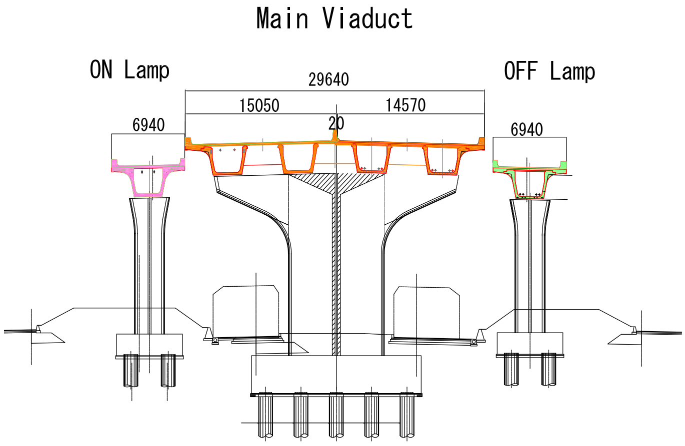


Fig.-1 Cross section of the viaduct

2. OUTLINE OF THE U-SHAPED GIRDER LIFTING ERECTION

The U-shaped girder lifting erection is the segmental construction, in which the U-shaped long precast prestressed concrete girders and the precast pier segments are fabricated at the casting yard in the construction site and the girders are then transported and erected. In case of this project, at most 240 ton of the U girder was lifted with the erection girder. After erection, the precast panels are placed on the girders and then cast-in-situ concrete slab was cast. Schematic construction flow is shown in Fig.-4.

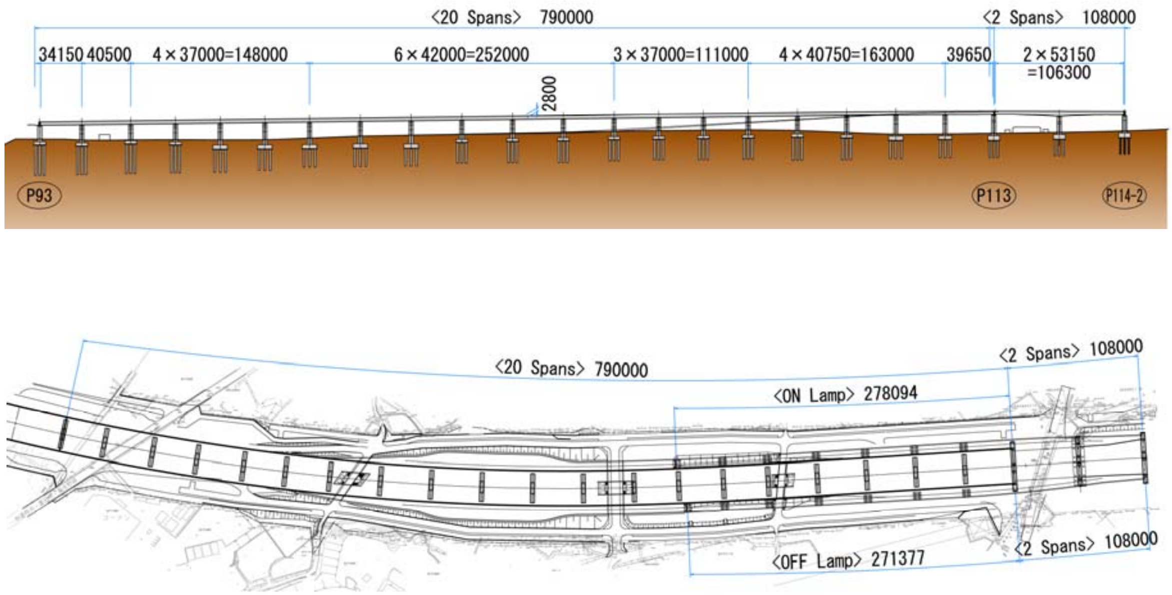


Fig.-2 Layout of the Nasu-dukuri Viaduct

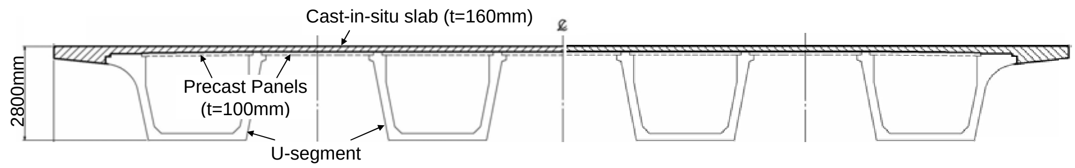


Fig.-3 Typical cross section

The U-shaped segments were practically applied to Furukawa viaduct on the New Meishin Expressway[1)] in Japan. Upper slab was cast lately after all the segments were erected and stressed, and the precast panels were placed at previously erected span. The advantage of the segment is to reduce the weight of the segment as well as to reduce the weight of the erection girder itself.

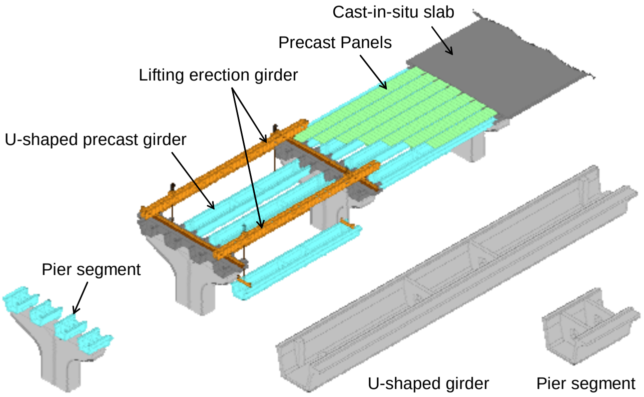
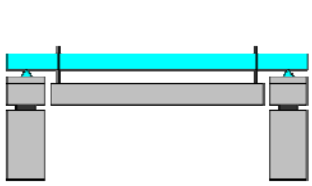
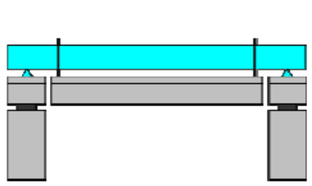
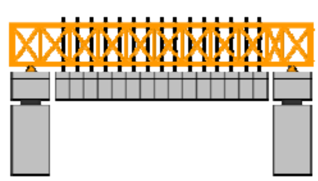
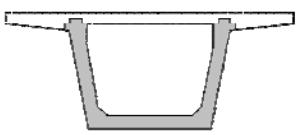
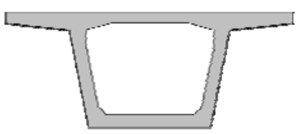
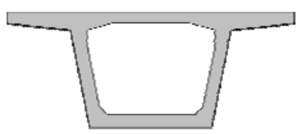


Fig.-4 Overview of the U-shaped girder lifting erection

Moreover, compared with the conventional span-by-span erection, this construction method could reduce the bending moment acting on the erection girder more effectively when hanging the concrete girder or segments. In general, relatively heavy erection girder is required for the span-by-erection in precast segmental construction where all the segments are hanged simultaneously with the erection girder. On the other hand in this project, a long U-girder is lifted near the supports of the erection girder. Therefore, the force acting on the erection girder could be much smaller. This also makes the erection girder further lightened. The bending moment which acts on the erection girder in this viaduct could be reduced to approximately 1/6 compared with the conventional span-by-span erection method (Table-2).

Table-2 Erection methods and the bending moments of the erection girder

Erection Method	U-Shaped girder lifting	Box girder lifting	Conventional span by span
			
Cross Section at Erection	U-Section	Box section	Box section
			
Max Bending Moment in Erection girder	4100 kN·m	6800 kN·m	23000 kN·m
	18%	30%	100%

The construction procedures are shown as followed (Fig.-5).

Step 1　Installation of the bearing on the piers
Step 2　Erection of pier segments
Step 3　Casting concrete to the crossbeam of pier segments
Step 4　Erection of the U-shaped girder
Step 5　Placing precast panels on the girders
Step 6　Cast-in-situ concrete of upper slab.

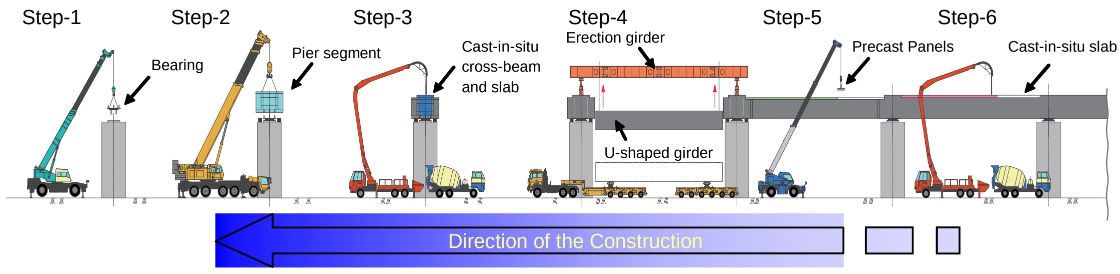


Fig.-5 Construction sequences

3. DESIGN

3-1. Outline of Design

All the construction phases as well as the service limit state and the ultimate limit state were designed. Since the structure changes in the construction phases, the prestressing cables were arranged and tensioned in several times according to the stress in the superstructures.

Arrangement of the prestressing cables for the average span is shown in Fig.-6. Max. 8 pre-grouted internal cables of 1S28.6 were arranged and tensioned inside the concrete section of the U girder at the casting bed as the primary cable. Then 4 external cables of 19S15.2 are arranged inside the U girder. 2 of 4 external cables were tensioned after the U girder was erected and after the cast-in-situ adjustment concrete joint was cast. These 2 cables are arranged in every single span as the secondary cables and remained 2 cables were tensioned after cast-in-situ slab in every 2 continuous spans as the third cables.

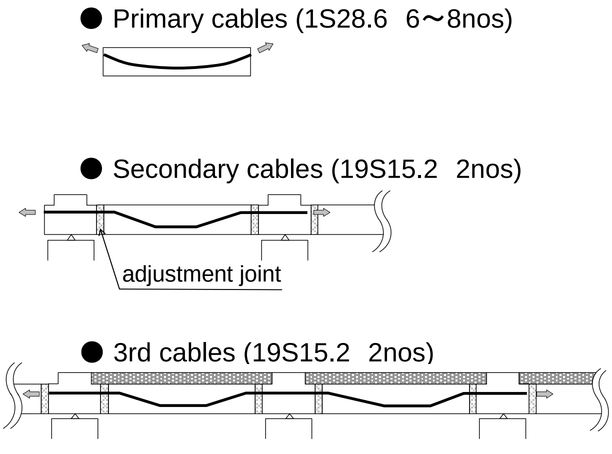


Fig.-6 Arrangement of prestressing cables

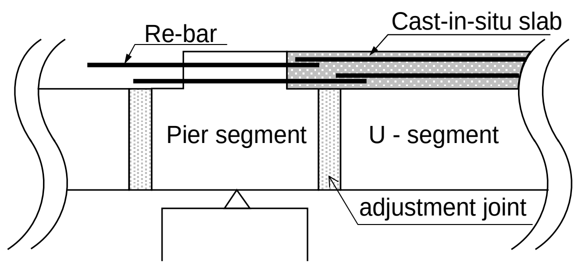


Fig.-7 Re-bars of the slab on the pier

Cast-in-situ adjustment joint was placed between pier segment and the U girder. The length of the joints are 100 mm -150 mm. In order to enhance the efficient construction work, the longitudinal reinforcement is not continued at the adjustment joint in the web and lower slab, while the reinforcement in the upper slab which was cast lately is arranged continuously (Fig.-7).

3-2. Design at erection stage

Since the U girder with no upper slab is an open cross section and the stiffness is relatively small compared with conventional box section, relatively large transversal deformation is caused until the upper slab was constructed, especially at lifting the girder, compared with conventional box girder. The local stress is also observed in the webs near the edge of the girder due to the transversal deformation. In order to strengthen the webs and to make the deformation smaller, vertical concrete ribs are attached. The ribs are also used for installing the temporary lifting devices as shown in Fig. 8. The temporary lifting devices are attached to the ducts in the ribs. The deformation and the stress in the girder during lifting are shown in Fig.-9 and Fig.-10. When lifting the girder at the webs, the stress in the webs with ribs in the U-section could be reduced.

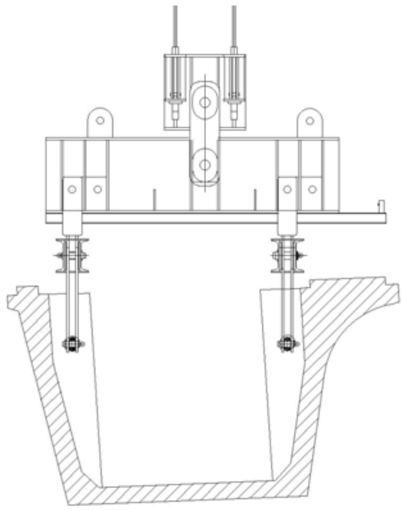


Fig.-8 Ribs and lifting devices

Moreover, the U girder has also small torsional stiffness due to the open cross section. During lifting, transversal deformation of the webs are restricted by ribs. However, about 1.3 mm-radians of the torsional deformation occur at mid-span in the outer girder since there is the overhang slab in the outer girder and the cross section is not symmetry. The asymmetric cross section cases the torsional stress not only transversally but also longitudinally, even when loaded uniformly. Tensile stress is also occurred at the outer edge of the web and lower slab in the outer girder in the longitudinal direction caused by the torsional deformation. Then additional longitudinal pre-grouted prestressing steel was arranged along the webs.

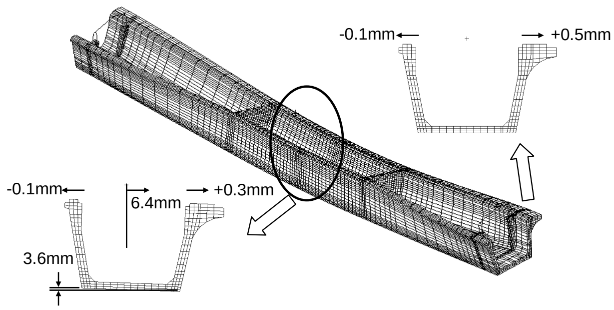


Fig.-9 Deformation of the girder at lifting

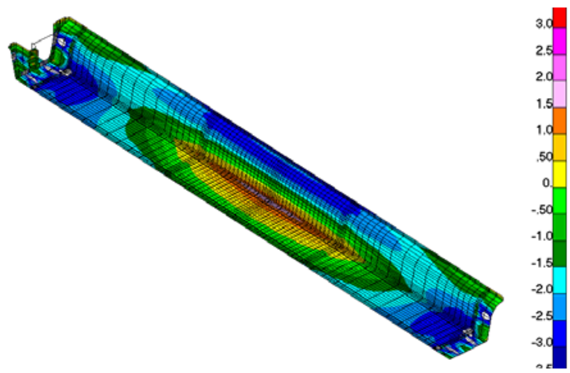


Fig.-10 Longitudinal stresses at lifting

The local stress near the lifting duct in the rib is shown in Fig.-11 and the local stress around the lifting duct with vertical prestressing is shown in Fig.-12.

The large vertical tensile stress occurs in the ribs and the webs, and the maximum tensile stress with no strengthening reaches around 5.6 MPa in the rib. The temporary vertical prestressing bar was arranged near the lifting duct in the rib to improve the tensile stress. As a result, the stress is improved as shown in Fig.-12. The remained resultant tensile stress occurs mainly in two zones, the one is at the top of the rib transversally, and the other is at the side of the rib around the duct vertically.

Additional reinforcement was arranged against both tensile stress zones. The lifting device was located at the 600mm lower from the top of the U girder so that the tensile stress in the edge on the rib could be less than 3 MPa and the re-bars of D22 were arranged against the tensile stress.

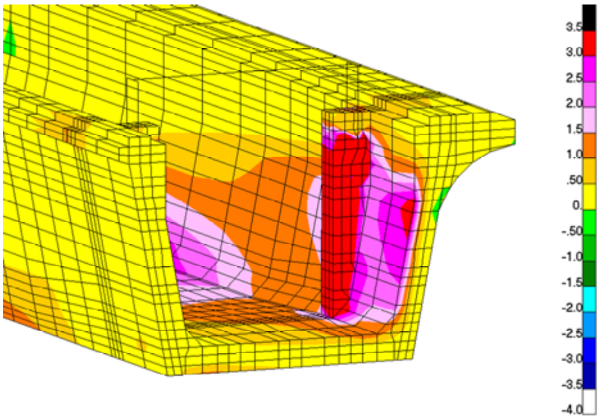


Fig.-11 Stress near the rib

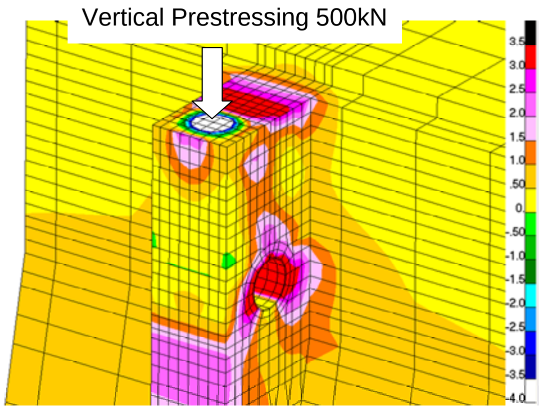


Fig.-12 Stress at lifting with vertical prestressing

4. MOCKUP VERIFICATION TEST

As mentioned, the large tensile stresses occur at the ribs during the erection of the U girder. Design was conducted with the three-dimensional FEA and the additional temporary prestressing bars were arranged. In order to confirm the design and the behavior of the structure, a mockup test was conducted. A part of the U girder was lifted to understand the stress and the deformation at the actual lifting load and also to understand the failure mechanism at the uneven loading under the unexpected situation. The load was increased up to 2 times of the design lifting load. The test specimen was a mockup of 3 m length from the edge of the long U girder. Precast panels were placed and cast-in-situ concrete of upper slab was also cast. The mockup test and the loading situation are shown in Photo-1 and Photo-2.

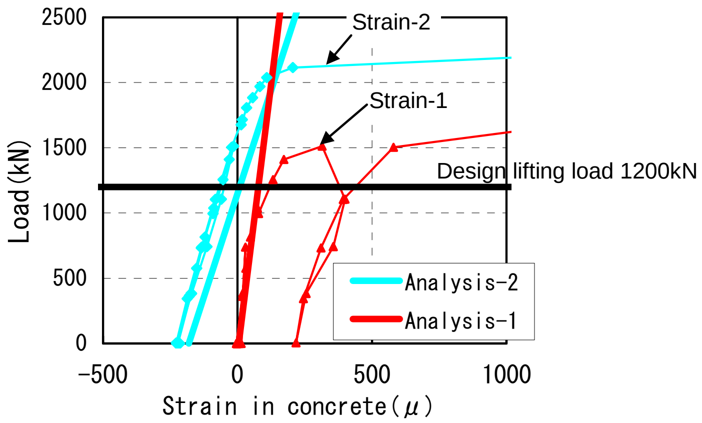


Fig.-13 Strain in concrete in the rib

The relation between the load and the concrete strain is shown in Fig.-13. As predicted in the

Photo-1 Overview of the mockup test

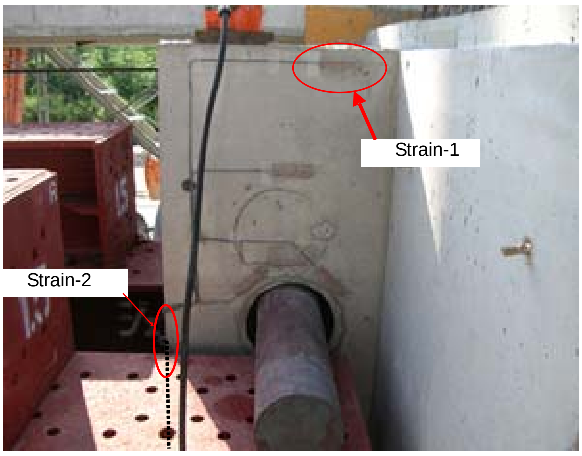


Photo-2 Loading situation

analysis, the first crack occurred above the lifting duct vertically when loading at 1600kN, which is 1.3 times of design lifting load. Then the load was increased up to 2 times of design lifting load, and it was confirmed that the crack width above the lifting duct developed at most 0.1 mm.

On the other hand, the local tensile stress at the side of the lifting duct, in which the rib is reinforced with the vertical prestressing bar arranged for strengthening the rib. When loading, no crack was observed even at 1.7 times of design lifting load and almost invisible minor crack was observed at 2 times of design lifting load. It was also confirmed that the crack did not extend to the web.

5. CONSTRUCTION

5-1. Fabrication and erection of the pier segment

Prior to the erection of the U girder, the pier segments were fabricated and erected (Photo-3). Since many numbers of the external cable anchorages and much reinforcement are arranged in the pier segment, the construction cycle of the pier segment could be critical compared with the fabrication and the erection of the U girder.

In order for the pier segment not to be in the critical path, the segments are also pre-fabricated. The configuration of U-shaped segment with thin crossbeam was selected to reduce the weight, and the massive concrete portion of the crossbeam was filled between the crossbeams as the cast-in-situ concrete and the upper slab was cast on it. 4 nos. of casting beds were used.

5-2. Fabrication of the U girder

The fabrication of the 4 nos. of U girders in a span is scheduled to catch up the erection of the U girders in order to minimize the casting yard. 4 casting beds were used as a reult, no temporary stock yard for the segments near the site was required. The casting yard of the U girders is shown in Photo-4.

To cast the 4 nos. of girders in the limited area, the area of the casting yard was reduced with the following measures.

- 4 sets of casting bed were arranged longitudinally along the narrow side road in the site (Photo-4).
- Re-bars and prestressing cables are pre-assembled.

Reduction of cycle work became possible by efficient work through avoiding the concentration of different types of work.

Photo-3 Erection of pier segment

Photo-4 Casting yard

Photo-5 U girder on the trailer at casting yard

Photo-6 Transportation of the girder

5-3. Transportation and erection of the U girder

After the U girder was fabricated, the U girder was transported on the large trailers from the casting bed to the erecting span along the sideways in the site (Photo-5, Photo-6).

The U girder was loaded and supported on the front and the rear wheels under the webs on the trailer. The enough care was taken for the U girder transportation supported on the wheel against the inclination of the girder and the torsion during transportation even on the uneven road surface.

Photo-7 and Pho-8 show the erection of the U girder. When lifting the U girder, a temporary balancing beam was installed for lifting the girder.

After lifting the U girder to the appropriate height with erection girder, the U girder was re-hung with the temporary equipment attached on the pier segments, and the position was re-adjusted.

The tensile forces were measured in all the 4 hanging steel rods and all the tensile force in steel rods were monitored when adjusting the position of the both ends of the U girder in order to control the stress due to the unexpected deformation and the positioning of the girder were finished. After the allowable influence to the stress in the U girder caused by the error of the elevation was verified in the design, the elevation was controlled so that an error of transversal inclination could be less than 0.2 %.

Photo-7 Overview of erection

Photo-8 Erection of the U girder

5-4. Transportation of the erection girder

Since the sideways of the viaduct are available as the construction yard in the viaduct in Nasu-dukuri Area, the large crane could be positioned in the sideway. This made the mechanism of the erection girder could be much simple.

After erection of the U girder and the construction of the adjustment joints between the U girder and the pier segments, 2 nos. of external cables were installed and tensioned. Then the erection girder was removed from the just erected U girder toward the next span. The cranes were used and the lifting girder was moved to the next span as followed (Photo-9).

- Put the erection girder on the trailer with a large crane
- Move to the next span
- Assemble the erection girder on the next span with the large cranes

5-5. Construction of slab

The slab is a composite structure, which consists of the precast panels and the cast-in-situ concrete. The panels are used as the embedded formwork for the cast-in-situ slab and the panels have the uneven surface to be unified with the cast-in-situ concrete as a structural member.

Approximately 260 precast panels were placed on the girders in a span (Photo-10). Standard size of the panel has 3.3 m length and 1.0 m width. The panels were erected with crane.

After the panels were placed, the slab reinforcement was arranged and the concrete was placed (Photo-11).

During casting the slab, the thermal stress and the restricted stress caused by the existing adjacent concrete slab were designed. Time dependent thermal analysis against these stresses was conducted and the early-age cracking in slab were prevented applying the additional re-bars and the expansive admixture in concrete.

AFTERWARD

The project was completed successfully on March, 2009 (Photo-12). This construction method is thought to be one of the new developments of the precast segmental construction which has further developed rapidly in recent years and could show the good example in the construction time reduction, the quality of the structures, the environmental protection around the construction area and the cost saving.

REFERENCE

1) S. Ikeda, H. Ikeda, K. Mizuguchi, K. Muroda and Y. Taira: Design and Construction of Furukawa Viaduct, Proceeding of the first fib congress, 2002

Photo-10 Precast panels

Photo-11 Cast-in-situ slab

Photo-12 Viaduct in Nasu-dukuri Area